In re Patent Application of:
VIGIL ET AL.
Serial No. **09/840,481**
Filing Date: **April 23, 2001**
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REMARKS

Applicants would like to thank the Examiner for the thorough examination of the present application. Please note that the Applicants are now being represented by the registered patent attorneys/agents listed on the enclosed Power of Attorney.

A substitute specification is being submitted to correct minor grammatical errors. In addition, original Claims 1-24 are being cancelled and new Claims 25-47 are being added. No new matter is being added. FIGS. 1-10 are being labeled as prior art, and an extraneous element is being removed from FIG. 11.

To overcome the double patenting rejection, Application Serial No. 09/845,663 is being expressly abandoned. The arguments supporting patentability of the new claims are presented in detail below.

I. The Claims Are Patentable

The Examiner rejected the original claims based upon the Grabb et al. patent, and alternatively, over the Welles, II et al. patent. The following arguments are directed to new independent Claims 25, 31, 35 and 42 in view of these prior art references.

The present invention, as recited in independent Claim 25, for example, is directed to method for mitigating multipath in a digital television signal (DTV). The method comprises multiplexing reference data with DTV data to generate a multiplexed DTV data stream, and modulating the multiplexed DTV data stream for transmission. The method further comprises receiving a transmitted DTV signal,

detecting correlation peaks in the received DTV signal based upon the multiplexed reference data, and using the detected correlation peaks to mitigate multipath in the received DTV signal.

The present invention advantageously mitigates multipath by modulating the DTV data along with reference data. The reference data allows a receiver to detect correlation peaks in the received DTV signal based upon the multiplexed reference data, and the detected correlation peaks are used to mitigate multipath in the received DTV signal.

Referring now to the Grabb et al. patent, and to FIG. 1 in particular, a wideband overlay sequence generator **103** provides an overlay signal that is added to the DTV signal to be transmitted. The overlay signal allows a receiver to estimate the transmission channel and allow mitigation of changing multipath conditions. In particular, periodic correlation peaks are detected in the received overlay signal, and the timing and magnitudes of the peaks in the received overlay signal are used to mitigate multipath in the received signal.

The overlay signal in Grabb et al. is added after the DTV data has been modulated. Reference is directed to column 4, lines 8-14 of Grabb et al., which provides:

> "For the present invention, <u>the DTV transmitter overlays an ultra wideband, relatively low power noise-like transmission centered on its associated 8-VSB (vestigial sideband) DTV signal</u> in order to provide a convenient and highly effective way to fine-grain characterize the outdoor and indoor multipath limited channel in order that the multipath

> effects may be mitigated and the ghosts significantly reduced." (Emphasis added.)

In other words, the DTV data to be transmitted is first modulated (i.e., 8-VDB modulation), then the overlay signal is added via adder **104** prior to transmission.

In sharp contrast, independent Claim 25 recites that the reference data is multiplexed with the DTV data before being modulated. Since the DTV data and the reference data are multiplexed prior to modulation, they are less likely to interfere with one another during transmission. In Grabb et al., since the overlay signal and the DTV signal are added together after modulation, they are more likely to interfere with one another during transmission.

Referring now to the Welles, II et al. patent, a pilot tone is added to a modulated DTV signal prior to being transmitted. Reference is directed to FIG. 1, and to column 2, lines 23-35 of Welles, II et al., which provides:

> "FIG. 1 shows a transmitting system **10** according to one embodiment of the invention in which a pilot tone is amplitude modulated prior to insertion in the transmitted signal. More particularly, the broadcast studio equipment **11** generates a digital bit stream of video and audio program signals which is provided to an ATSC encoder **12** that generates an output signal to a transmitter **13**; that is, in the ATSC format, studio equipment **11** converts the audio and video program into a stream of bits which is used by ATSC encoder **12** to modulate the transmitter **13** output signal in a manner known as eight level vestigial sideband (8-VSB) modulation. A pilot tone

> generated by a pilot tone generator **14** is added to the 8-VSB signal at a summer **15**." (Emphasis added.)

As with the Grabb et al. patent, the pilot tone is added after the DTV data has been modulated. In sharp contrast, independent Claim 25 recites that the reference data is multiplexed with the DTV data before being modulated. Since the DTV data and the reference data are multiplexed prior to modulation, they are less likely to interfere with one another during transmission. In Welles, II et al., since the pilot tone and the DTV signal are added together after modulation, they are more likely to interfere with one another during transmission.

Accordingly, it is submitted that independent Claim 25 is patentable over Grabb et al., and alternatively, over Welles, II et al. Independent Claims 31, 35 and 42 are similar to independent Claim 25. Accordingly, it is also submitted that independent Claims 25, 31, 35 and 42 are patentable over Grabb et al., and alternatively, over Welles, II et al. In view of the patentability of independent Claims 25, 31, 35 and 42, it is submitted that their dependent claims, which recite yet further distinguishing features of the invention, are also patentable. These dependent claims require no further discussion herein.

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CONCLUSION

In view of the new claims and the arguments provided herein, it is submitted that all the claims are patentable. Accordingly, a Notice of Allowance is requested in due course. Should any minor informalities need to be addressed, the Examiner is encouraged to contact the undersigned attorney at the telephone number listed below.

Respectfully submitted,

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CERTIFICATE OF MAILING

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Justin Gore

MARKED-UP VERSION OF SUBSTITUTE SPECIFICATION

~~TITLE OF THE INVENTION~~

~~Method of Effective Backwards Compatible ATSC DTV~~
~~Multipath Equalization Through Training Symbol Induction~~

~~REFERENCES TO PRIOR ART~~

~~5,592,235~~	~~1/7/1997~~	~~Park et al.~~
~~5,802,241~~	~~9/1/98~~	~~Oshima~~
~~5,886,748~~	~~3/23/99~~	~~Lee~~
~~5,923,378~~	~~7/13/99~~	~~Limberg~~
~~5,943,372~~	~~8/24/99~~	~~Gans et al.~~

~~RELEVANT STANDARDS~~

~~*ATSC Digital Television Standard*, Doc. A/53, Advanced Television Systems Committee, September 16, 1995~~

~~BACKGROUND OF THE INVENTION~~

SUBSTITUTE SPECIFICATION

METHOD FOR ATSC DTV MULTIPATH EQUALIZATION AND ASSOCIATED DEVICES

Related Application

[0001] The present application is based upon copending provisional patent application no. 60/201,537 filed April 24, 2000, the entire contents of which are incorporated herein by reference.

Field of the Invention

[0002] The present invention relates to ~~D~~digital ~~T~~television (DTV) ~~in general~~, and ~~specifically~~ in particular, to the ~~A~~advanced ~~T~~television ~~S~~systems ~~C~~committee (ATSC) standard for terrestrial broadcast television in the United States.

Background of the Invention

[0003] The ATSC DTV standard was determined by the "Grand Alliance" and was subsequently accepted by the broadcast community, the consumer electronics industry and the regulatory infrastructure. The regulatory infrastructure has mandated a strict~~ly scheduled transition~~ schedule for the transition of terrestrial broadcast television in the United States from the ~~N~~national ~~T~~television ~~S~~system ~~C~~committee (~~"NTSC" or~~

~~"analog") standard to the ATSC ("digital") standard. At the time of this disclosure, a~~NTSC) to the ATSC standard. The NTSC standard is an analog standard whereas the ATSC is a digital standard. A significant investment is in place, on behalf of the broadcast industry, ~~in terms of substantial progress in cooperation with~~to support th~~e~~is planned transition. Similarly, many consumers have purchased ATSC television receiver equipment in the form of new ATSC-system compliant DTV television sets and in the form of DTV television set-top converters.

[0004] However, the ATSC standard, in its present form, is deficient in its susceptibility to multipath. ~~It is well known that in~~In a side-by-side comparison~~s~~, ~~ATSC (~~reception of the new digital system~~) reception~~ ATSC standard is often inferior to ~~NTSC (~~reception of the conventional analog system~~) reception~~ NTSC standard. Additionally, ATSC mobile reception ~~is observed to~~ suffers a more substantial degradation due to multipath than NTSC mobile reception. It is also well known that signal strength and signal-to-noise ratios (SNR) are not at issue. Unanticipated inferior reception manifests itself at high levels of received signal power and at high receiver signal-to-noise ratios ~~(SNR's)~~. This fact, coupled with spectral analysis of received ATSC DTV signals, points directly to multipath as the cause of inferior reception.

~~Various inventors have disclosed significant~~

[0005] Significant work in the area of DTV reception~~. Included in this work is Park et al. in 5,592,235, issued January 7, 1997, which describes means of efficiently combining reception, appropriate to~~ is available. For example, U.S. Patent No. 5,592,235 to

Park et al. describes terrestrial broadcast reception and~~ to~~ cable broadcast~~, both~~ reception in a single receiver. ~~Also included in this work is Oshima in 5,802,241, issued September 1, 1998, which~~U.S. Patent No. 5,802,241 to Oshima describes a plurality of modulation components modulated by a plurality of signal components.

~~The use of decision feedback~~

[0006] Decision-feedback equalizers (DFE) have been used in digital demodulation~~ is a matter of prior art~~. Unfortunately, ~~DFE~~decision-feedback equalization is not suitable for enabling the initial acquisition of digital modulation severely distorted by multipath-induced intersymbol interference. For this purpose, a reference waveform or reference sequence is typically introduced. The use of a reference sequence equalizer is ~~considered by Lee~~ disclosed in U.S. Patent No. 5,886,748~~, issued March 23, 1999~~ to Lee, which describes in very general terms the use of a reference sequence for equalizing ~~"GA-HDTV"~~GA-HDTV signals. ~~Unfortunately~~However, ~~the cited work~~Lee does not address the multipath issues relevant to ATSC DTV reception. ~~Neither~~In addition, Lee does ~~this work~~not address the compatibility between the referenced ~~"training~~training sequence" with the existing ATSC DTV standard~~. Nor~~, and does ~~the cited work~~not address the relevance or appropriateness of the referenced training sequence and equalization method to VHF and UHF multipath~~, whose impact on ATSC DTV reception was discovered after the fact of the cited work.~~

~~Also of importance to the present introduction of~~.

[0007] Also of interest to terrestrial ATSC DTV in the United States is ~~the work by Limberg in 5,923,378,~~

~~issued July 13, 1999. This work addresses NTSC-to-DTV~~U.S. Patent No. 5,923,378 to Limberg. Limberg addresses NTSC to DTV interference issues relevant to the DTV transition plan in effect in the United States. Also of interest is ~~the work by Gans et al. in 5,943,372, issued August 24, 1999, which introduces~~U.S. Patent No. 5,943,372 to Gans et al., which discloses the combination of diversity transmission with complementary forward error correction. Unfortunately, none of the~~ cited works constitutes~~se prior art references provide an effective remedy ~~in~~for multipath with respect to the~~ context of ATSC standard~~ ATSC DTV standard for terrestrial broadcast DTV.

~~**BRIEF SUMMARY OF THE INVENTION**~~

~~The~~

Summary of the Invention

[0008] In view of the foregoing background, an object of the present invention is to reduce the susceptibility of the ATSC DTV standard to multipath for terrestrial broadcast DTV.

[0009] This and other objects, advantages and features in accordance with the present invention ~~addresses the strategy of enabling "reference" or "training" "sequence" or "waveform"~~are provided by a method that enables a reference or training sequence or waveform equalization by introducing an equalizer training waveform compatibl~~y~~e with the present ATSC DTV standard for terrestrial broadcast DTV in the United States.

[00010] A training waveform is ~~induced~~introduced into the ATSC DTV modulation waveform by introducing training sequence placeholders onto the ATSC DTV multiplex and transport. Subsequent processing yields

modulation training suitable for allowing ~~and tailored to enabling~~ the adaptive equalization processes required at the receiver to address VHF and UHF multipath. The necessary transmission signal processing is accomplished with no hostile effects in terms of backward compatibility with pre-existing legacy ATSC DTV receivers. The training waveform ~~as such~~ is ~~induced~~introduced specifically to enable training-waveform-based equalization that is adequate and necessary to address ~~multipath-induced~~multipath induced intersymbol interference otherwise known to be catastrophic to ATSC DTV reception.

[00011] ATSC DTV modulation is preserved and ATSC DTV multiplex and transport remain compatible with the existing ATSC DTV standard. As such, the existing ATSC DTV infrastructure is compatible with the disclosed ATSC DTV multipath ~~solution~~approach. ~~Every existing~~Existing ATSC DTV receivers continue~~s~~ to function as ~~it~~they ha~~s~~ve functioned before.

[00012] Retrofit of pre-existing consumer ATSC DTV receiver equipment is unnecessary. However, the production of new consumer ATSC DTV receiver equipment is made possible, through this disclosure, with minimum economic disruption. The practical cost and complexity of the necessary transmission equipment upgrade is ~~minimized~~reduced through ~~the exploitation of~~ the backwards-compatible ATSC DTV multiplex and transport training sequence induction technique disclosed herein. ~~S~~In addition, a substantial and significant advantage with respect to multipath equalization processing is ~~enabled through the exploitation of the backward compatible ATSC DTV modulation and transmission training waveform induction technique disclosed.~~

~~**BRIEF DESCRIPTION OF THE DRAWINGS**~~

~~Fig~~also obtained.

Brief Description of the Drawings

[00013] FIG. 1 is a general block diagram of an ATSC DTV transmission system in accordance with the prior art.

[00014] FIG. 2 illustrates an ATSC DTV modulation frame for the ATSC DTV transmission system ~~i.a.w. (in accordance with) the ATSC DTV standard [*ATSC Digital Television Standard*, ATSC document number A/53].~~

~~Fig. 2 illustrates the ATSC DTV modulation frame i.a.w. the same standard.~~

~~Fig~~shown in FIG. 1.

[00015] FIG. 3 is a conceptual illustration of multipath in accordance with the prior art.

[00016] F~~ig~~IG. 4 is a~~ simplified~~ block diagram of ~~the~~a continuous-time modulator and channel model in accordance with the prior art.

[00017] F~~ig~~IG. 5 is a block diagram ~~illustrating~~of an equivalent time-sampled modulator and channel model in accordance with the prior art.

[00018] F~~ig~~IG. 6 is a block diagram of an adaptive blind equalizer in accordance with the prior art.

[00019] F~~ig~~IG. 7 is a block diagram of an adaptive decision-feedback equalizer in accordance with the prior art.

[00020] F~~ig~~IG. 8 is a block diagram of an adaptive training waveform equalizer in accordance with the prior art.

[00021] F~~ig~~IG. 9 is a simplified block diagram of~~ the~~ ATSC DTV transmission and reception systems in accordance with the prior art.

[00022] ~~Fig~~IG. 10 is a simplified block diagram of ATSC DTV transmission and reception systems retrofitted for ~~standard noncompliant~~standard noncompliant training waveforms in accordance with the prior art.

[00023] ~~Fig~~IG. 11 is a simplified block diagram of ATSC DTV transmission and reception systems retrofitted for backwards-compatible induced equalizer training symbols in accordance with the present invention.

[00024] ~~Fig~~IG. 12 is a general block diagram of the ATSC DTV transmission system~~ i.a.w. the ATSC DTV standard [*ATSC Digital Television Standard*],~~ highlighting the data interleaving process in the presence of training sequence induction data in accordance with the present invention.

[00025] ~~Fig~~IG. 13 illustrates the introduction of induction packet sequences at ~~the~~a rate of 1 induction packet per 13 ATSC DTV multiplex packets in accordance with the present invention.

[00026] ~~Fig~~IG. 14 illustrates the ATSC DTV byte interleave process i~~.a.w.~~n accordance with the ~~ATSC DTV standard [*ATSC Digital Television Standard*]~~present invention.

[00027] ~~Fig~~IG. 15 illustrates an example where an interleaved frame has been formed by introducing 1 induction packet per 6 ATSC DTV multiplex packets in accordance with the present invention.

[00028] ~~Fig~~IG. 16 illustrates the ATSC DTV TCM byte interleave process i~~.a.w.~~n accordance with the ~~ATSC DTV standard [*ATSC Digital Television Standard*]~~present invention.

[00029] ~~Fig~~IG. 17 illustrates the ATSC DTV TCM bit interleave process i~~.a.w.~~n accordance with the ~~ATSC DTV~~

~~standard [*ATSC Digital Television Standard*]~~present invention.

[00030] F~~ig~~IG. 18 illustrates the ATSC DTV TCM encode process ~~i.a.w. the ATSC DTV standard [*ATSC Digital Television Standard*].~~in accordance with the present invention.

~~**DETAILED DESCRIPTION OF THE INVENTION**~~

Detailed Description of the Preferred Embodiments

[00031] The ATSC DTV transmission system is illustrated in F~~ig~~IG. 1. The transmission system includes a multiplexe~~s~~r **125** for multiplexing various components of the broadcast program, including video **105**, audio **110**, data **115** and control information **120**. The service multiplex stream **130** is randomized by a randomizer **135**, Reed-Solomon encoded by an RS encoder **140**, byte-interleaved by a data interleave circuit **145** and TCM encoded by a Trellis encoder **150** in preparation for modulation. Modulation ~~consists of the introduction **165** of~~includes introducing a segment sync **155** and a field sync **160**~~, **adddition of a pilot**~~ to a multiplexer **165**, then adding a pilot signal at a pilot insert circuit **170**, followed by ~~preequalization~~pre-equalization by a pre-equalization filter **175**, VSB modulation by a VSB modulator **180** and RF ~~upconversion~~up-conversion by a converter **185**. The modulation format is commonly described in terms of the ~~"~~ATSC DTV modulation frame~~"~~ as best illustrated in F~~ig~~IG. 2.

[00032] The foremost weakness of the ATSC DTV standard for terrestrial broadcast digital television is its susceptibility to multipath. F~~ig~~IG. 3 illustrates the dilemma caused by multipath. The propagation path from

the broadcast transmitter site **310** to any given receiver ~~sight~~site (~~"NTSC"~~an NTSC site **380** or ~~"DTV"~~a DTV site **390**) may involve any whole number ~~(zero or more)~~ of propagation paths **320, 330, 340, 350, 360** and **370**. Each ~~independent or unique~~ propagation path **320, 330, 340, 350, 360** and **370** has an independent or unique amplitude, as well as delay and phase characteristics. ~~The~~

[00033] A customary consumer antenna does not distinguish from multiple paths. Such a process (multiple antennas or phased ~~arrays~~array antennas) is beyond the capability of conventional consumer electronic equipment ~~customary for~~ used in television reception. Consequently, each received signal from each of ~~multiple~~the propagation paths **320, 330, 340, 350, 360** and **370** contributes either constructively or destructively with respect to ~~each~~the other received ~~signal from each other associated path **320, 330, 340, 350, 360** and **370**~~signals. It is more likely that two or more ~~multiple~~propagation paths **320, 330, 340, 350, 360** and **370** add destructively rather than constructively. The complication of multiple additive amplitudes, phases and delay responses yields a received signal subject to unpredictable linear time and frequency distortion ~~or~~, i.e., self-interference.

[00034] ~~Again in~~Still referring to F~~ig~~IG. 3~~, on the right side of the figure~~, an NTSC (conventional analog) receiver **380** is shown above ~~and~~ a DTV (ATSC standard digital) receiver **390** ~~is shown below~~. This aspect of F~~ig~~IG. 3 serves to illustrate the present dilemma faced by the broadcast industry. In the case of the conventional analog ~~"NTSC"~~NTSC system **380** ~~depicted above~~, multipath manifests itself in terms of analog

interference. The resulting program distortion manifests itself primarily as ~~"ghosting~~ghosting.~~"~~ ~~"Ghosts"~~Ghosts of the analog image ~~consist of~~includes superimposed copies of the ~~intended~~ picture appearing over the intended picture in the video display. Ghosts are commonly observed in terrestrially received NTSC video images. ~~This v~~Video image ghosting is sometimes tolerable to the viewer, as ghosting may or may not be substantially significant in terms of image degradation. This is in contrast to the multipath distortion effects commonly observed in ~~new digital "ATSC" 390 DTV~~the reception ~~described~~of digital signals from an ATSC system **390**.

[00035] With respect to the ATSC modulation waveform, multipath manifests itself in intersymbol interference. Intersymbol interference is known~~,~~ in ~~the~~ ATSC system~~,~~s to cause catastrophic failures. There is no ~~"ghosting"~~ghosting or ~~"graceful~~graceful degradation.~~"~~ The signal is simply lost (SNR ~~"cliff~~cliff effect~~"~~) or it is never acquired (when intersymbol interference violates demodulation signal acquisition thresholds). In the former case, the visible result is image ~~"freezing"~~freezing or ~~"deresolution"~~deresolution due to the loss of data. ~~In the former case, t~~The audible result is ~~muting~~muted (loss of audio). In the latter case, the visible result is a blank screen and silent audio. Based on these observations, and on their corresponding frequency of occurrence, one skilled in the art of television reception arrives at the conclusion that the ATSC DTV standard format, in its present form, ~~constitutes~~presents a service ~~downgrade~~degradation with respect to reception reliability.

[00036] Multipath may be modeled in continuous time as a linear convolutional process $h(t,\tau)$ **440** as shown in F~~ig~~IG. 4. In this figure, the symbol sequence $x(n)$ **410** is applied to the modulator **420**~~,~~ for producing a modulation waveform $s(t)$ **430**. The propagation channel is represented by the convolutional process $h(t,\tau)$ **440** and the additive **470** noise process $n(t)$ **460**. The resulting signal $r(t)$ **480** is received at the ATSC DTV receiver.

[00037] The modulation and channel propagation processes lend themselves to a time-sampled representation as shown in F~~ig~~IG. 5. In this figure, the modulation signal $s(n)$ **530** is modeled as a time-sampled waveform in time index n. Although the same time index is used for the symbol sequence $x(n)$ **410**, it is important to note that "N ~~-~~x sampling" ("i.e., N-times sampling") is common to digital signal processing ~~relevant~~with respect to both~~ the~~ transmission and reception systems. The use of the same time index for both waveforms is not intended to preclude the use of "N ´ sampling~~" in this application~~. The modulation symbol sequence $x(n)$ **410** in time index n is to be thought of as adhering to the identical "N ´ sampling" process and ~~consisting of~~includes repeated sets of "N-1" "zero" samples interspersed with single symbol states.

~~Nor should~~

[00038] In addition, the absence of complex notation throughout this application should not be misconstrued

as to preclude the use of complex sampling. Complex sampling is both anticipated and expected, and is omitted in this application merely for the sake of simplifying the disclosure.

[00039] In F~~ig~~IG. 5, the same linear convolutional multipath response $h(t,\tau)$ **440** is modeled as a time-sampled vector process $\overline{h}(n,m)$ **540** where is the time index and m is the time-response index, indicating a "vector" sampled-time response in m at every time sample n. Lastly, channel noise **560** is added **570** on a sample-by-sample basis to yield the received time-sampled waveform $r(n)$ **580**.

[00040] This time-sampled model is applied to the drawings, which illustrate the prior art as applied to ATSC DTV equalization. F~~ig~~IG. 6 illustrates a blind equalizer used to adaptively converge ~~**650**~~ on a sufficiently accurate approximation $\hat{\overline{h^{-1}}}(n,m)$ **610** of the inverse $\overline{h^{-1}}(n,m)$ of the channel response $\overline{h}(n,m)$ **540** using an adaptive algorithm **650**. F~~ig~~IG. 7 illustrates the decision feedback equalizer applied ~~to~~for the same purpose. A training waveform equalizer is illustrated in F~~ig~~IG. 8. In all cases, the prior art has failed to produce a suitable equalizer and/or demodulator ~~capable of~~for reliably receiving the conventional ATSC DTV terrestrial broadcast waveform in the presence of significant multipath.

[00041] An inherent weakness of the ATSC DTV standard system, as illustrated in the simplified block diagram

of ~~Fig~~IG. 9, is the 24.2 ms interval **220** (as illustrated in FIG. 2) between successive field sync elements **160** in the modulation frame~~, illustrated in Fig. 2~~. If used for equalizer training, the interval **220** is not short enough to enable receivers to accurately track temporal multipath variations quickly enough to yield effective reception. One possible ~~solution~~approach is to explicitly introduce field sync elements **16~~1~~0** more frequently into the modulation frame. The required system modifications are illustrated in ~~Fig~~IG. 10. Such a~~ solution~~n approach would be politically detrimental in that it would render existing ATSC DTV transmission and reception equipment obsolete. As such, the direct addition of supplemental training waveform components is economically ~~untenable~~unjustifiable.

[00042] An economically viable ~~solution~~approach requires ~~"~~backward compatibility~~"~~ with existing receivers. Such a~~ solution~~n approach may be identified by the following ~~marks.~~comments:

1. Enables continuous reliable viewing in the presence of significant multipath channel impairments;

2. ~~"~~Significant multipath channel impairments~~"~~ to include ~~"~~ghosts~~"~~ generated by reflections and/or obstructions moving at 100 kilometers per hour (~~>~~ 6~~0~~2 MPH) with respect to reception equipment;

3. This approach is done while every pre-existing legacy ATSC DTV receiver ~~a)~~ receives the same signal ~~b)~~, and to the extent that it can be received in the absence of any transmission waveform modifications.

[00043] The present invention ~~consists of~~comprises a method of introducing new, more frequent training symbols into the modulation frame through backward compatible induction. F~~ig~~IG. 11 illustrates the necessary modifications to~~ the~~ ATSC DTV transmission and reception systems. In this method, ~~"~~supplemental training sequence~~"~~ data **1110** is introduced into the service multiplexer **125** in the form of periodic packets ~~**1110**~~. Such packets are formed with the ATSC DTV standard in mind and in such a manner as to induce frequent and advantageous training symbol components **1120** into the ATSC DTV modulation frame (as illustrated in F~~ig~~IG. 2).

[00044] The operation of the training symbol induction method is best described by example. In ~~the~~a first example, one training symbol packet is introduced into the service ~~multiplex~~multiplexer **125** after every 12 conventional MPEG-2 service multiplex packets. The effective service rate is reduced by 1/13 @ 8% in the interest of inducing the advantageous frequent training symbol components.

[00045] F~~ig~~IG. 12 emphasizes the introduction of the training symbol packet data **1110** and the subsequent interleave processing **145**, inherent to ~~ATSC DTV~~the ATSC DTV standard transmission, which has the effect of distributing the induced training symbols throughout the modulation frame (as illustrated in F~~ig~~IG. 2).

[00046] F~~ig~~IG. 13 illustrates the sequence of new supplemental training symbol packets **1110** and conventional MPEG-2 multiplex packets **1310** at the output of the service multiplexer **125**. F~~ig~~IG. 14 illustrates the interleave process **145** i~~.a.w.~~n accordance with the ATSC DTV standard.

[00047] The distribution of MPEG-2 training symbol bytes by the interleaver **145** in the modulation frame (F~~ig~~IG. 2) is illustrated in F~~ig~~IG. 15 using an example where 1 training sequence packet is introduced per 5 conventional MPEG-2 data packets, or 6 total MPEG-2 packets. In this illustration, every box represents a byte of multiplexed data read left-to-right, then top-to-bottom. The numbered boxes indicate the positions of the post-interleave training symbol bytes i~~.a.w.~~n accordance with the ATSC DTV standard byte interleave process **145**. In this manner, each byte of each training sequence packet **1110** in the service multiplexer **125** is mapped through the interleave process **145**. Not shown is the addition ~~**140**~~ of Reed-Solomon (R/S) ~~checkbytes~~check bytes **140** to each service multiplex packet i~~.a.w. ATSC DTV~~n accordance with the ATSC DTV standard transmission practice.

[00048] Subsequent ~~ATSC DTV~~ATSC DTV standard processing is required before corresponding new supplemental training symbols **1120** are manifested into the DTV modulation frame (F~~ig~~IG. 2). The ~~byte-interleaved~~byte interleaved service multiplex, which is the output of the byte interleaver **145**, is applied to a TCM (trellis-coded modulation) byte interleaver as shown in F~~ig~~IG. 16. Each of the 12 parallel TCM encode processes **1650** involve bit interleaving as shown in F~~ig~~IG. 17 and TCM encoding as shown in F~~ig~~IG. 18. In the induction method disclosed, each induction data bit is mapped from the interleaved service multiplex data stream (output of byte interleaver **145**) to the modulation frame (per the ATSC ~~S~~standard as illustrated in F~~ig~~IG. 2) in the same manner that the induction data packet

bytes were mapped through the R/S encode process and subsequent byte interleave process into the interleaved service multiplex data stream (in the manner of F~~ig~~IG. 15).

[00049] The essence of this method is the exploitation of th~~is~~e mapping to induce frequent regular periodic training symbol components into the modulation frame so as to enable effective multipath reception at the compatible receiver while maintaining backwards-compatibility with pre-existing legacy reception equipment. It is important that the training symbol components induced into the ATSC DTV modulation frame be of sufficient number and frequency as to enable effective multipath reception. Such a frequency and number ~~is~~are determined by evaluating relevant propagation parameters.

[00050] The first relevant propagation parameter is the multipath delay spread. The relevant VHF and UHF multipath delay spreads are on the order of up to 100 ms. Another relevant propagation parameter is the highest transmission frequency. This frequency $f_{\max}$ corresponds to the highest terrestrial broadcast television channel~~,~~:

$$f_{\max} \cong 800\,\mathrm{MHz}$$

The minimum transmission wavelength $\lambda_{\min}$ is computed from the highest transmission frequency $f_{\max}$ using:

$$\lambda_{\min} \cong \frac{c}{f_{\max}} \cong \frac{3\times10^{8}}{800\times10^{6}} \cong .375\ \mathrm{m}$$

The maximum multipath reflection component velocity $v_{\max}$ is calculated in terms of the maximum number of wavelengths per second from the 100 kph benchmark as follows~~.~~:

$$v_{\max} \cong 2\times100\,\mathrm{kph} \cong 200\,\mathrm{kph} \cong 200\,\mathrm{kph}\times\frac{1000\,\mathrm{m}}{\mathrm{km}}\times\frac{1\,\mathrm{hr}}{3600\,\mathrm{s}}\times\frac{\lambda_{\min}}{.375\,\mathrm{m}} \cong 150\frac{\lambda_{\min}}{\mathrm{s}}$$

[00051] The corresponding minimum multipath-ray phase-change or phase-rotation periodicity $T_{reflection}$ is calculated from this $v_{\max}$ using:

$$T_{reflection} \cong \frac{1}{150} \cong \frac{7\,\mathrm{ms}}{\lambda_{\min}}$$

Finally, experience indicates the prudence of offering provisions for updating multipath equalizers more than 10 times per minimum path variation cycle interval. Using instead a more conservative factor of 20, the recommended equalizer update interval is calculated to be

$$T_{update} \cong \frac{7\,\text{ms}}{\lambda_{\min}} \times \frac{\lambda_{\min}}{20\,\text{updates}}$$

$$< \quad 350\,\mu\text{s}$$

or

$$T_{update} < 350\,\mu\text{s}$$

In summary, adequate ATSC DTV multipath equalization calls for equalization of delay spreads on the order of up to 100 ms at update intervals of less than 350 ms.

[00052] The preferred embodiment is derived from the following comments:

1. ~~t~~The need to introduce training waveforms at intervals of less than 350 ms so that associated receivers can successfully track multipath using reliable ~~reference-trained~~reference trained equalizers;

2. ~~t~~The need to supply sufficient training symbols in each such training waveform so as to ensure the ability of trained equalizers to sufficiently train at the intervals indicated;

3. ~~t~~The need to match training waveform

periodicity with those of the pre-existing ATSC ~~s~~Standard;

4. ~~t~~The need to keep the enhancement simple; and

5. ~~t~~The need to restrict the introduction of training symbols to a reasonably small percentage of the system data throughput so as to preserve information capacity.

[00053] The preferred embodiment ~~consists of~~includes the introduction of 4 induction packets per 52 multiplex packets. Periodicity is essential~~, as it is essential~~ so that the receiver ~~be~~is able to find the induced reference symbols. A periodicity of 52 multiplex packets is chosen because 52 multiplex packets divides evenly into the 624 multiplex packets which map into the ATSC DTV modulation frame and into the 12-branch TCM encode interleave process i~~.a.w.~~n accordance with the ATSC DTV standard (52 ´ 12 = 624).

[00054] In the preferred embodiment, 4 induction packets per 52 service multiplex packets map into approximately 96 full training symbols per 3 modulation segments (232 ms) plus 96 partial training symbols. These second 96 "partial" training symbols are "partial" in the sense that their state cannot be fully controlled due to the two-bit delay **1820** inherent in the ~~ATSC-DTV~~ATSC DTV standard TCM encoding process, as illustrated in F~~ig~~IG. 18. Their state may only be partially controlled in the sense that the bit which is not subject to convolutional coding delay is used to map the major component of the symbol state as opposed to the entire symbol state. The relevant correlation processing gain is approximated using

$$10 \log(96 \times 1.5) > 20\,\mathrm{dB}$$

~~offering~~which offers greater than 20 dB processing gain ~~with which~~ to resolve the channel response.

[00055] As such, the preferred embodiment offers adequate and sufficiently frequent means to characterize multipath suitably for reliable ATSC DTV receiver channel characterization and demodulation, or to otherwise serve as a reference against which to train the corresponding equalizers.

[00056] Also ~~crucial~~important to the successful implementation of the training symbol induction method is the necessity to ensure compatibility of the induction packets with existing receivers. It is necessary that pre-existing legacy receivers "reject" such packets. This is accomplished through one or both of the following techniques:

1. The induction process verifies or causes training symbol induction packets to be invalid and "uncorrectable" R/S codewords (distance > 10 R/S characters to nearest valid codeword) so as to be discarded by the receiver; and

2. The induction process causes training symbol induction packets to be associated with an unused MPEG-2 program channel so as to be discarded by the receiver.

[00057] The data overhead associated with either of these processes does not cause an appreciable degradation to the > 20 dB processing gain associated with the preferred embodiment described above. Of significance to the method disclosed is the fact that induced training symbols do not typically appear contiguously in the modulation frame, but are instead

typically interspersed between data symbols. The result is that a longer time base is used to formulate each channel multipath approximation.

[00058] The preferred embodiment at the receiver is to ~~employ~~use a reference-trained equalizer such as the one illustrated in F~~ig~~IG. 8. Such an equalizer would exploit the sufficiently frequent training waveform and the a-priori knowledge of training symbol locations to find the training symbols and to train the equalizer against them. Measures to acquire and maintain symbol and modulation frame timing would be required.

[00059] An alternative reception method involves the following:

1. Use of a correlator to determine a sufficiently accurate approximation $\hat{\bar{h}}(n,m)$ for the multipath channel response $\bar{h}(n,m)$ **540** at every training waveform interval; and

2. Use of an LMS, RLS or other relevant technique to approximate the necessary inverse-channel function $\overline{h^{-1}}(n,m)$ **610** required in the implementation of the required equalizer $\hat{\overline{h^{-1}}}(n,m)$ **610**.

[00060] In terms of the correlator, an objection may be raised in terms of anticipated complexity. However, a very computationally efficient correlator is constructed as follows~~.~~:

1. ~~Whereas ATSC DTV~~ATSC DTV 8-VSB symbol states (-7, -5, -3, -1, 1, 3, 5 and 7) are offset i~~.a.w.~~n accordance with the ATSC DTV standard by a

pilot of magnitude ~~"~~1.25,~~"~~ but the effective symbol states become (-5.75, -3.75, -1.75, 0.25, 2.25, 4.25, 6.25 and 8.25);

2. A reasonable and acceptable approximation to these states are the states (-6, -4, -2, 0, 2, 4, 6 and 8);

3. Correlation of a 96 ´ 2 = 192 symbol sequence involves 192 multiplies per point, which is extremely computationally intensive. However, the required multiplies, subject to the approximation above, may instead be implemented in fixed-point arithmetic using successive bit-shifts and adds (i.e., multiplication by 4 is a 2-bit shift; multiplication by 6 is the sum of the results of a 1-bit shift and a 2-bit shift). The resulting implementation significantly reduces ~~computational burden.~~computations; and

4. A minor modification of the ATSC DTV standard ~~consisting of~~includes a change in the pilot level from 1.25 to 1 renders the above approximation (step 2) exact.

[00061] The preferred reception method involves the use of the correlator as described above to acquire and maintain symbol and frame timing while ~~employing~~using the reference-trained equalization process of F~~ig~~IG. 8 to suppress multipath-induced intersymbol interference.

~~CLAIMS~~THAT WHICH IS CLAIMED IS:

~~What is claimed is:~~

Sub B1

1. A method of introducing legacy-compatible supplemental training waveform components into ATSC-compatible DTV transmission waveforms by exploiting ancillary data capability in said standard.

2. A method of introducing said legacy-compatible supplemental training waveform components per claim 1 by anticipating transmission signal processing, and compensating for same, in the generation and queueing of relevant ancillary data packets so as to induce the designed training waveform components, while preserving enough information in relevant ancillary data packets so as to allow legacy and future receivers to distinguish these training waveform induction packets from desired information-bearing packets.

3. A method of introducing said legacy-compatible supplemental training waveform components per claim 1 at the transmission point by introducing appropriate "placeholder" packets in the packet data stream, then generating intentionally designed supplemental training waveform components in the modulation waveform at time instances corresponding to those which map from the "placeholder" training symbol induction packets while passing sufficient data, undisturbed, from same placeholder packets so as to cause legacy and future receivers to distinguish those

placeholder packets from desired information-bearing packets.

4. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into ATSC-compatible DTV transmission waveforms per the method of claim 1, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through signaling means available through spare capacity in the ATSC DTV field sync segment or otherwise.

5. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into ATSC-compatible DTV transmission waveforms per the method of claim 1, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through signaling means available through information payload packets, or portions of information payload packets, designated for use as such.

6. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into ATSC-compatible DTV transmission waveforms per the method of claim 1, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through its correlation properties.

7. A method of gradually improving multipath resilience of ATSC DTV standard broadcast and reception systems by gradually introducing, over time, various legacy-compatible supplementary training or reference waveforms for inclusion, selectably or otherwise, per the method of claim 1.

8. A method of designing legacy-compatible supplemental training waveform components for introduction per method of claim 1 so as to derive maximum benefit, with respect to equalization subject to known channel multipath characteristics, through appropriate selection of length, periodicity and processing gain of same said supplemental training waveform components, said selection subject to pre-existing ATSC DTV transmission signal periodicities and configuration.

9. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 1 by employing those components to more quickly, frequently and/or reliably train pre-demodulation equalizers.

10. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 1 by passing the received transmission waveform through a correlator, digital or otherwise, to extract multipath channel response characteristics for use in more quickly, frequently and/or reliably training pre-demodulation equalizers.

11. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 1 by passing the received transmission waveform through a digital correlator, said correlator implemented with reduced complexity based on the use of bit shifts and sign changes instead of multiplication, yielding a correlator implementation limited to addition operations or to addition operations and a minimum number of bit shifts, and said correlation process for the purpose of extracting multipath channel response characteristics for use in more quickly, frequently and/or reliably training pre-demodulation equalizers.

12. The method of modifying the ATSC DTV standard transmission format by reducing pilot signal amplitude by 20% in the interest of subsequently reducing computational complexity required of correlation-based training-waveform processing, or in the interest of improving the accuracy of said reduced-complexity correlators over the accuracy possible with the presently specified pilot amplitude.

13. A method of introducing legacy-compatible supplemental training waveform components into digital transmissions in general by exploiting packet-based information payloads.

14. A method of introducing said legacy-compatible supplemental training waveform components per claim 13 by anticipating transmission signal processing, and compensating for same, in the

generation and queueing of relevant ancillary data packets so as to induce the intentionally designed training waveform components while preserving enough information in relevant ancillary data packets so as to allow legacy and future receivers to distinguish these training waveform induction packets from desired information-bearing packets.

15. A method of introducing said legacy-compatible supplemental training waveform components per claim 13 at the transmission point by introducing appropriate "placeholder" packets in the packet data stream, then generating designed supplemental training waveform components in the modulation waveform at time instances corresponding to those which map from the "placeholder" training symbol induction packets while passing sufficient data, undisturbed, from same placeholder packets so as to cause legacy and future receivers to distinguish those placeholder packets from desired information-bearing packets.

16. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into digital transmission waveforms per the method of claim 13, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through signaling means available through spare capacity in the modulation fields designed to convey configuration and control overhead information.

17. A method of introducing zero, one or more

selectable legacy-compatible supplemental training waveform components into digital transmission waveforms ATSC-compatible DTV transmission waveforms per the method of claim 13, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through signaling means available through information payload packets, or portions of information payload packets, designated for use as such.

18. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into digital transmission waveforms per the method of claim 13, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through new signaling means introduced into the legacy modulation waveform.

19. A method of introducing zero, one or more selectable legacy-compatible supplemental training waveform components into digital transmission waveforms ATSC-compatible DTV transmission waveforms per the method of claim 13, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through signaling means available through newly configured information payload packets, or new portions of legacy standard information payload packets, introduced for use as such.

20. A method of introducing zero, one or more

selectable legacy-compatible supplemental training waveform components into ATSC-compatible DTV transmission waveforms per the method of claim 13, said training waveforms selected from a plurality or ensemble of selections, where each selection or combination of selections is identifiable to the receiver through its correlation properties.

21. A method of designing legacy-compatible supplemental training waveform components for introduction per method of claim 13 so as to derive maximum benefit, with respect to equalization subject to known channel multipath characteristics, through appropriate selection of length, periodicity and processing gain of same said supplemental training waveform components, said selection subject to pre-existing digital transmission signal periodicities and configuration and to payload packet periodicities and configuration.

22. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 13 by employing those components to more quickly, frequently and/or reliably train pre-demodulation equalizers.

23. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 13 by passing the received transmission waveform through a correlator, digital or otherwise, to extract multipath channel response characteristics for use in more

quickly, frequently and/or reliably training pre-demodulation equalizers.

24. A method of exploiting, at the receiver, said legacy-compatible supplemental training waveform components introduced per method of claim 13 by passing the received transmission waveform through a digital correlator, said correlator implemented with reduced complexity based on the use of bit shifts and sign changes instead of multiplication, yielding a correlator implementation limited to addition operations or to addition operations and a minimum number of bit shifts, and said correlation process for the purpose of extracting multipath channel response characteristics for use in more quickly, frequently and/or reliably training pre-demodulation equalizers.

~~**ABSTRACT OF THE DISCLOSURE**~~

~~This invention enables improved reception of ATSC terrestrial broadcast~~ METHOD FOR ATSC DTV MULTIPATH EQUALIZATION AND ASSOCIATED DEVICES

Abstract of the Disclosure

A method for mitigating multipath in a digital television ~~signals. ATSC DTV is a standard of the Advanced Television Systems Committee (ATSC) for the terrestrial broadcast of digital television. ATSC DTV broadcast signals are subject to impairment due to multipath. Improved radio reception in multipath is possible when substantial reference components are transmitted as a component of~~signal (DTV) includes multiplexing reference data with DTV data to generate a multiplexed DTV data stream, and modulating the multiplexed DTV data stream for transmission. After the transmitted ~~radio. However, the introduction of new signal components to the ATSC DTV broadcast signal represents a modification to the standard which weaken the benefits of standardization. This invention resolves this dilemma by carefully introducing data components into the data multiplex in a form compatible with the ATSC DTV standard. Data components are chosen so as to induce a substantial repeating reference component into the ATSC DTV modulation waveform. The induced reference waveform enables clear reception in multipath while the integrity of the standard is preserved.~~DTV signal is received, correlation peaks are detecting based upon the multiplexed reference data. The detected correlation peaks are used to mitigate multipath in the received DTV signal.